AMT EXPERIMENT RESULTS

Mr. Brian S. Abbe and Ms. Deborah S. Pinck
Jet Propulsion Laboratory
California Institute of Technology
M.S. 238-420
4800 Oak Grove Drive
Pasadena, California 91109
Voice: (81 8) 354-3887 FAX: (81 8) 354-6825
e-mail: abbe@bvd.jpl.nasa.gov

ABSTRACT

The Advanced Communications Technology Satellite (ACTS) Mobile Terminal (AMT) experiments have provided a terminal technology testbed for the evaluation of K- and Ka-band mobile satellite communications (satcom). Such a system could prove to be highly beneficial for many different commerical and government mobile satcom users. Combining ACTS' highly concentrated spotbeams with the smaller, higher-gain Ka-band antenna technology, results in a system design that can support a much higher throughput capacity than today's commercial configurations. To date, experiments in such diverse areas as emergency medical applications, enhanced Personal Communication Services (PCS), disaster recovery assistance, military applications, and general voice and data services have already been evaluated. Other applications that will be evaluated over the next year include telemedicine, ISDN, and television network return feed, Baseline AMT performance results will be presented, including Bit Error Rate (BER) curves and mobile propagation data characterizing the K- and Ka-band mobile satcom channel, In addition, observations from many of the application-specific experiments will also be provided.

INTRODUCTION

Throughout the eighties NASA, through JPL, has been involved in the development and demonstration of system concepts and high risk technologies to enable the introduction of commercial mobile satellite services (MSS). This initial effort occurred at L-band (1.5 GHz), and currently commercial L-band MSS are available through a host of U.S. and international companies. It is expected that the present allocation for L-band MSS will become saturated by the turn of the century. In view of this, and the already existing non-MSS frequency allocations at other bands (C-, X-, and Ku-bands for example), NASA and JPL have focused on K- and Ka-bands for further expansion of MSS.

K- and Ka-bands have outstanding potential for higher data rate communications and more highly diversified MSS for a number of reasons. Unlike L-band, K- and Ka-bands have a significant amount of bandwidth (500 MHz at each K- and Ka-bands) already allocated for MSS services. Moreover, these higher frequencies can support antenna designs that while physically smaller than their L-band counterparts, can provide higher gain, often 10 dB or more, K- and Ka-bands, therefore, are excellent candidates for the pursuit of higher capacity services for commercial users (i.e., compressed video). However, satellite communication system design at these higher frequencies poses significant technical challenges including: a young technology with lossy RF components, significant rain attenuation effects, potentially large frequency uncertainties, and large Doppler shifts due to vehicular motion.

NASA has provided a platform for the initial evaluation and exploitation of K- and Ka-bands through their development of the ACTS. JPL's goal, through the use of ACTS and the development of the AMT, is to overcome these technical challenges with a system architecture and components that will exploit the potential benefits of such a migration from L-band. The final phase of this effort has been and continues to be the transfer of such technologies to interested groups within U.S. industry. By directly involving U.S. industry in these experiments, NASA hopes to expedite the commercialization of this technology.

The remainder of this paper provides a brief description of the ground terminal equipment and it's baseline performance in a series of internal JPL experiments. Furthermore, an explanation of the various experiments with US. industry that have been conducted or are in the process of being planned will be presented. Finally, the experiment results to date will be provided.

AMT DESCRIPTION

The complete technical details and architecture of this terminal can be found in. [1]. The AMT can be broken down into two broad divisions, namely, the baseband and microwave processors. The baseband processor consists of a speech codec, a modem, and a terminal controller (TC). Also included as part of this setup, strictly for experimental purposes, is a Data Acquisition System (DAS). The elements of the microwave processor are: the IF Converter (IFC), the RF Converter (RFC), the antenna controller, and the antenna.

The TC is the "brain" of the terminal. It contains the algorithms that translate the satcom protocol into operational procedures and interfaces to all of the other terminal subsystems. The TC is also responsible for providing the user with a system monitoring capability, and a variety of test functions during experimentation, such as bit stream generation and bit error rate (BER) calculations.

Two different modems have been used as part of the AMT. The baseline AMT modem, that was designed in-house, implements a simple yet robust DPSK scheme with rate 1/2 convolutional coding and interleaving. The performance specification for this modem is for a BER of 10-3 at an E_b/N_0 of 7 dB in AWGN. Further capabilities have been built into this modem to compensate for frequency offsets of up to 10 kHz with an additional performance degradation of only 0.5 dB. This modem is operational at 2,4, 4.8, and 9.6 kbps. The second modem that has been utilized as part of this setup is a commercially developed satcom modem that includes such features as coherent

BPSK with convolutional coding, concatenated coding (Reed-Solomon), and interleaving. The performance specification for this modem is for a BER of 10^{-6} at an E_b/N_o of 5 dB in AWGN. This modem is operational at data rates ranging from 9.6 kbps to 2.048 Mbps.

The vehicle antenna is the critical K-/Ka-band technology item in the microwave processor. The design of this antenna called for a “passive” elliptical reflector-type antenna to be used in conjunction with a separate high powered amplifier. Complete with a spherical radome, it stands approximately 5 inches in height, and is approximately 8 inches in diameter at its base. This antenna is fully tracking in azimuth, while manually positioned in elevation to one of five distinct settings.[1] Combined with a 10 W TWTA, this antenna system provides at least 32 dBW transmit EIRP on boresight. The 3 dB beamwidth is 12° in azimuth and 18° in elevation, Receive specifications for this antenna have been set at -5 dB/°K, once again on boresight.

The antenna pointing system enables the antenna to track the satellite for all practical land-mobile vehicle maneuvers. The antenna is mated to a simple, yet robust, mechanical steering system. A scheme wherein the antenna is smoothly dithered about its boresight by about a degree at a rate of 2 Hz is used. The pilot signal strength is measured through this dithering process, and is used to compliment the inertial rate sensor’s information. This information allows the antenna to track the satellite while experiencing a shadowing event of up to 10 seconds in duration.

Preceding (or following) the antenna, the RFC converts an IF signal around 3.373 GHz to (from) 30 (20) GHz for transmit (receive) purposes. The IFC translates signals between 3.373 GHz and a lower 70 MHz IF at the output (input) of (to) the modem. A key function of the IFC is pilot tracking and Doppler compensation (for the return communications link).

AMT BASELINE TEST RESULTS

BER **Results**

The initial baseline AMT tests collected fall into two categories: (1) terminal performance characterization (utilizing the baseline AMT modem) and (2) mobile satcom K- and Ka-band propagation characterization. Complete details of these tests can be found in [2], The single best method for determining the terminal’s performance were accomplished through a series of stationary BER tests. The test setup for the baseline system performance is provided in Figure 1. A set of baseline BER tests were performed from the fixed terminal (FT) to the mobile terminal (MT). PN sequence data was transmitted from the FT’s Terminal Controller (TC) and a final BER was determined at the MT’s counterpart, The E_b/N_o value was determined by the E_b/N_o

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[1] These five settings allow for complete elevation coverage for the continental United States.

box prior to and after the actual transmission of the PN sequence, once again using an unmodulated data signal. These two values were then averaged for the test run. This test was performed for all three of the lower operational data rates of the AMT (2.4/4 .8/9,6 kbps). Four different E_b/N_o values were recorded for each data rate corresponding to final BER values ranging between approximately 10-5 and 10"'. Several test conditions were established at the beginning and maintained throughout these tests to ensure consistent results. They are as follows: (1) the van was stationary, (2) the van's engine was turned off to minimize external noise sources (3) the power used in operating the terminal was supplied by the AC generator, (4) the mobile terminal's antenna pointing was accomplished in the manual mode to minimize any sources of error due to pointing (dithering), and (5) no pilot signal was transmitted to minimize the effects of intermodulation on-board the satellite.

The results of these BER tests for 9.6 kbps, 4.8 kbps, and 2.4 kbps are provided in Figures 2, 3, and 4, respectively. For comparison purposes, the pre-satellite test results, which utilized a satellite simulator, have also been included. These are listed as Xlator in the figures. Both of these results agree to within experimental error (0.25 dB or less) with each other. For terminal operation at a 9.6 kbps data rate, an E_b/N_o of 6.8 dB is required to achieve a BER of 10^{-3}. For the 4.8 and 2,4 kbps cases, this performance level is achieved for an E_b/N_o level of 6.7 and 8.5 dB, respectively. The significantly larger E_b/N_o requirement for the 2.4 kbps case can be attributed to higher sensitivity to system frequency offsets at this data rate.[2]

Propagation Test Results

The objectives of the mobile propagation experiments were to measure and analyze the fading characteristics of the K- and Ka-band channel. The analysis involved examining multipath, shadowing and blockage effects. Field tests were conducted in various environments; results presented here include 1) rural freeway runs free of obstructions except for occasional overpasses and 2) shadowed suburban runs with occasional obstructions from buildings, utility poles, and trees. Additional information on the propagation test results can be found in [3],

Data from the first category, that is rural freeway runs, was collected on Interstate 210 between California State Highway 2 and California State Highway 118. This is 15 mile east-west span. A map of this route is provided in Figure 5. A representative time series of the pilot power transmitted by the fixed station and received the AMT is shown in Figure 6. The statistics of the shadowing/fading are summarized by a histogram of the cumulative distribution of the pilot power received at the AMT. The histogram of the run shown in Figure 6 is provided in Figure 7. It can be seen that the 1 % fade level for the 20 GHz channel is 1 dB. This is typical for a clear line-of-sight (LOS) channel.

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[2] Residual frequency offsets in this particular system setup have been calculated to be several kHz in a worst case scenario.

Data from the second category, that is a shadowed suburban run, was collected on the roads the circle the Rose BowI in Pasadena, California. A map of this route is provided in Figure 8. The road is surrounded by rolling hills with substantial amounts of foliage. Figure 9 shows the time series for a test run around the Rose Bowl. The statistics of the shadowing/fading are summarized by the histogram in Figure 10 where it is seen that the 1 % fade level for the 20 GHz channel is 25dB. This corresponds to a moderately shadowed suburban environment.

The shape of each histogram is typical for mobile satellite channels. The slope from the reference level to 2-3 dB below is steep and consistent with a Ricean characteristic. A transition region, or "knee" (at 3-5 dB fade levels) precedes a less steep curve for deeper fades. This shallow curve is characteristic of heavy shadowing. These characteristic curves have also been observed on other K-band propagation experiments [4].

AMT EXPERIMENTS

As part of the ACTS Experiments Program, JPL has been given the task of seeking out useful applications for K- and Ka-band mobile satcom and to further demonstrate these capabilities through ACTS and the AMT. To date, twelve different experimenters involving several different government agencies, U.S. industrial interests, and academia have been officially approved to experiment with ACTS and the AMT by NASA Headquarters and the ACTS Project Office at NASA LeRC. The experiments period began in December 1993 and will continue for at least two years through November 1995. A summary of the mobile experiments is presented in Table 1. Many other experiments are still in the formative stage. Applications-oriented experiments and demonstrations in such areas as emergency medicine, personal communications (PCOMM), disastery recovery, military communications, telemedicine, direct broadcast, and satellite news gathering (SNG), have been or will be demonstrated.

It is clear that these applications for mobile satcom will result in a better overall quality of service within their respective fields. In fact, some of these applications could be offered with current commercial mobile satcom systems. The ACTS/AMT experiments that were conducted in emergency medicine and personal communications [5] could be supported today with existing commercial service (e.g., Inmarsat, AMSC) as they are low-bandwidth services. These experiments were conducted strictly to investigate the viability of offering these services via satellite. Other experiments would require an ACTS-like (higher capacity) K- and Ka-band system to fulfill their needs. Details on all of these experiments can be found in [6]. Further explanations on aeronautical mobile applications for K- and Ka-band may be found in [7]. The remainder of this section will focus on the satellite news gathering and telemedicine experiments.

NBC SNG Experiment

Current communication capabilities for mobile satellite news-gathering limited to cellular telephone service (where available). Furthermore, while communications can typically be expanded to include video capabilities once the SNG van is stationary, the setup is rather large and unwieldy, Utilizing ACTS and the AMT, a series of experiments and demonstrations were accomplished which overcame both of these deficiencies. A picture of the experimental van parked side by side with a typical operational SNG van is provided in Figure 11 (the experimental van is the one on the left). Note the tremendous size difference between the two vehicles' antennas, In addition, there is effectively no setup time required for the AMT.

Full-duplex compressed video communications at data rates up to 768 kbps, both fixed and mobile, was established between an experimental van located in the greater Los Angeles area and a fixed station located at NASA LeRC in Cleveland, Ohio. The communications link was further enhanced by terrestrially connecting (via a fractional T1 data line) the fixed station with NBC New Headquarters, New York. Two different types of video codecs were used in this experiment: ABL's VT2C and NEC's VisuaLinks 5000EX. Both of these video codecs worked well under the conditions that were experienced over the mobile satcom link.

University of Washington Medical Center Telemedicine Experiment

Vast regions of the United States do not have access to recent advances in medical technology. This particular experiment will link rural America to these technologies by connecting them to metropolitan areas and research hospitals associated with many universities. Specifically, the University of Washington Medical Center, known for their capabilities and advances in radiology, will be linked to various locations throughout the northwestern United States via ACTS and the AMT. This experiment is scheduled to take place during the summer of 1995. The data rates that are targeted for this experiment are 64 kbps and 128 kbps. The NEC VisuaLinks 5000EX will be utilized. One particular objective for these tests to evaluate is the quality of a transmitted 64 kbps or 128 kbps still image for reliable medical diagnosis, Medical applications such as X-Rays, Magnetic Resonance Images (MRI's), and Computed Topographies (CT's) will be evaluated.

SUMMARY

The development of ACTS and the AMT have been an excellent proof-of-concept technology testbed for K- and Ka-band mobile satcom. Through this work, many advancements have been made in the area of mobile satcom (i.e., several high gain, directional, tracking antenna schemes, a novel Doppler estimation and correction algorithm, etc.). Initial tests with the AMT suggest that this terminal's performance meets or exceeds that expected of the initial design. Through these developments, and the influx of experimenters with this equipment, it is hoped that NASA and JPL are contributing to the U.S. industrial community's technological advantage in this highly competitive field.

REFERENCES

[1] Dessouky, K. and Jedrey, T., "TheACTS Mobile Terminal (AMT)," Proceedings of the 14th AIAA Conference, March 22-26, 1992, Washington, D.C.

[2] Abbe, B. S., Miller, M. D., Nakamura, D. I., Pinck, D. S., "ACTS Mobile Terminal Experiments Test Results, Weekly Report for the Week of December 6, 1993.

[3] Rice, M. and Pinck, D., "K-Band Mobile Satellite Propagation Characteristics Using ACTS, URSI, Boulder, Colorado, January 1995.

[4] J, Goldhirsh and W. Vogel, "ACTS Mobile Propagation Campaign," Proceedings of the 18th NASA Propagation Experimenters Meeting, ppg. 135-150, Vancouver, British Columbia, June 1994.

[5] Pinck, D., Tong, L., McAuley, A., Kramer, M., "Satellite-Enhanced Personal Communications Experiment," International Mobile Satellite Conference 1995, June 6-8, Ottawa, Canada.

[6] Abbe, B. S., "ACTS Mobile Experiments Summary Description," November 11, 1993.

[7] Agan, M.J. and Densmore, A.C., "ACTS Broadband Aeronautical Terminal," International Mobile Satellite Conference 1995, June 6-8, Ottawa, Canada.

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Table 1 ACTS Mobile Experiments Summary

EXPERIMENT	PRINCIPAL INVESTIGATORS
Land-Mobile, Phase I	JPL
Emergency Medical	EMSAT Corporation
Secure Land-Mobile, Phase I	NCS
Comm-on-the-Move	U. S.. Army CECOM
Aero-X	NASA LeRC
Satellite/Terrestrial PCN	Bellcore
Satellite News Gathering	NBC
High Quality Audio Broadcast	CBS Radio, CCS
Telemedicine	Univ. of Washington Medical Center
Land-Mobile, Phase II	JPL
Secure Land Mobile, Phase II	NCS, JPL
Unmanned Ground Vehicle	ARPA

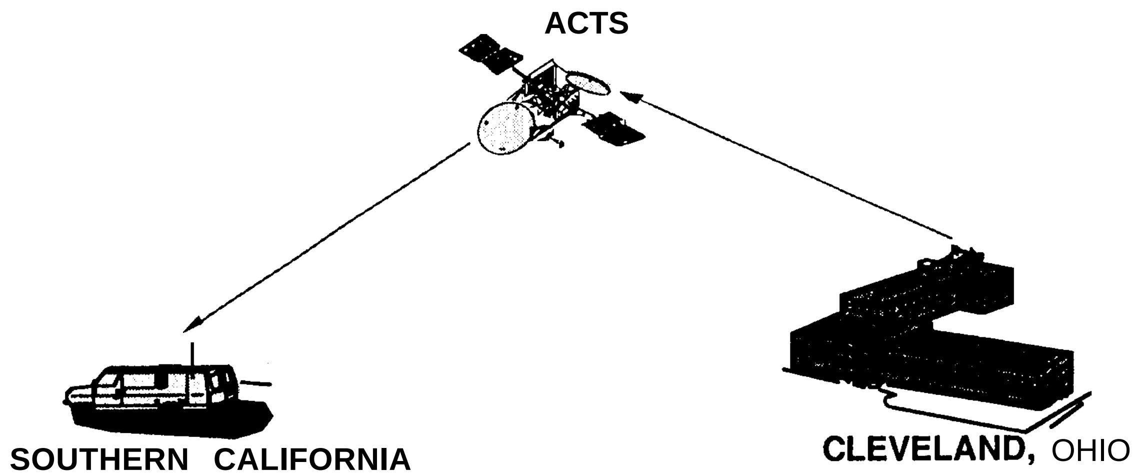

Figure 1 Baseline AMT System Performance Test Configuration

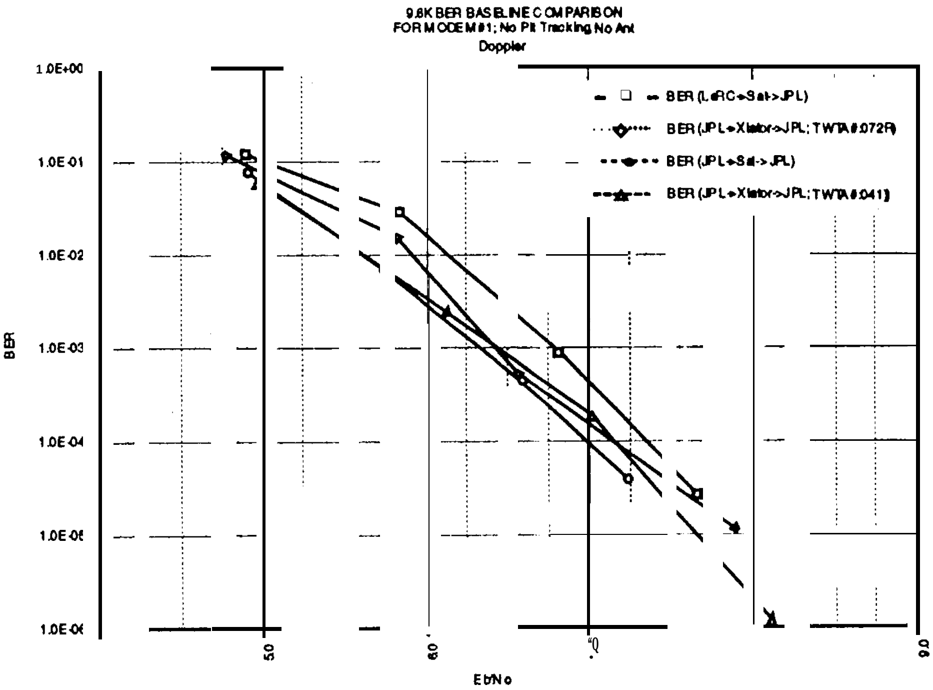

Figure 2 9.6 kbps BER Test Results

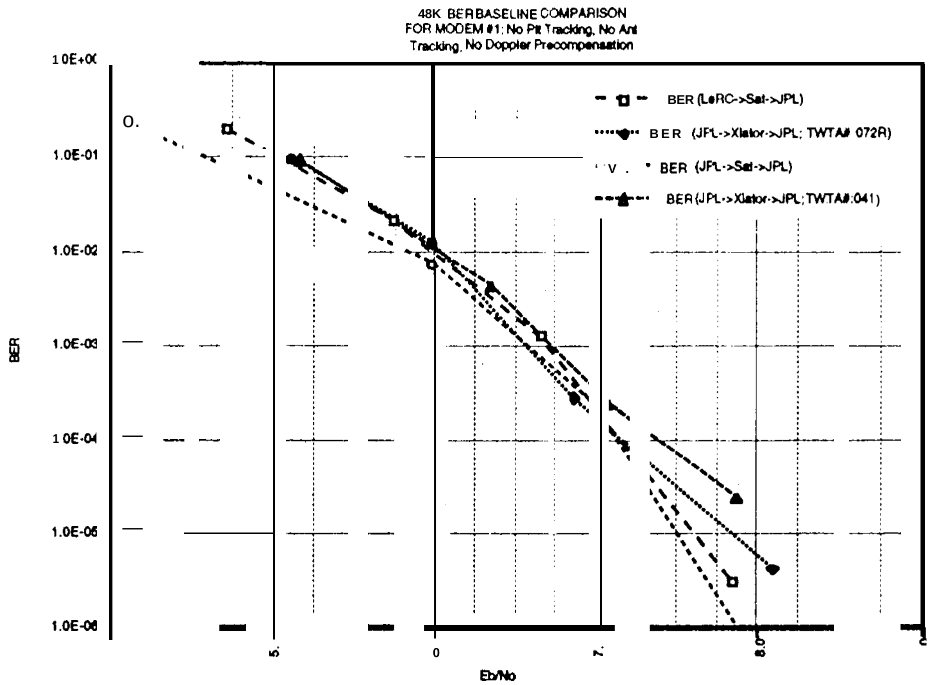

Figure 3 4.8 kbps BER Test Results

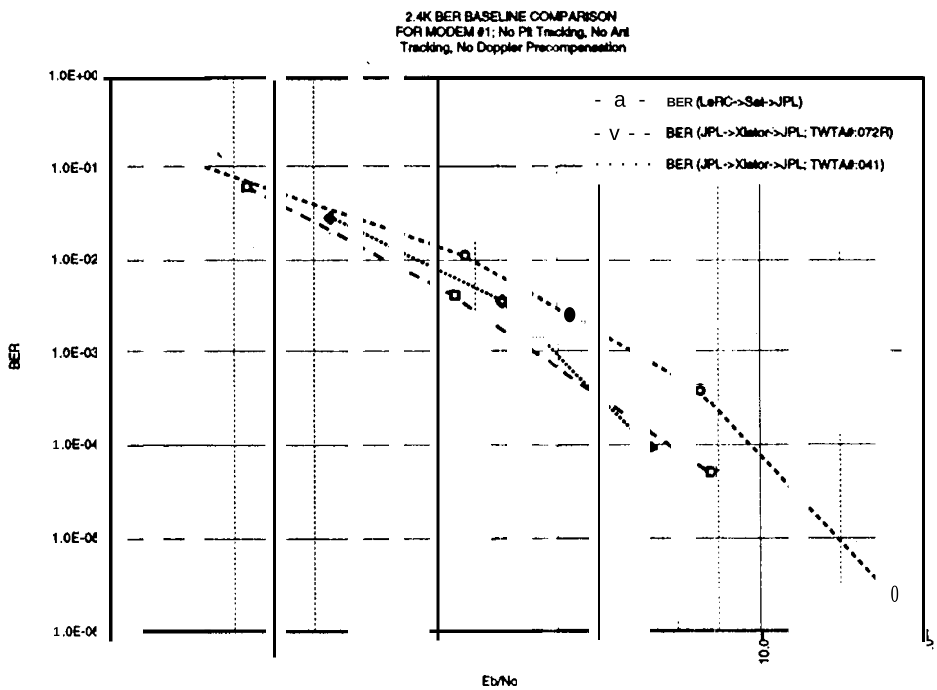

Figure 4 2.4 kbps BER Test Results

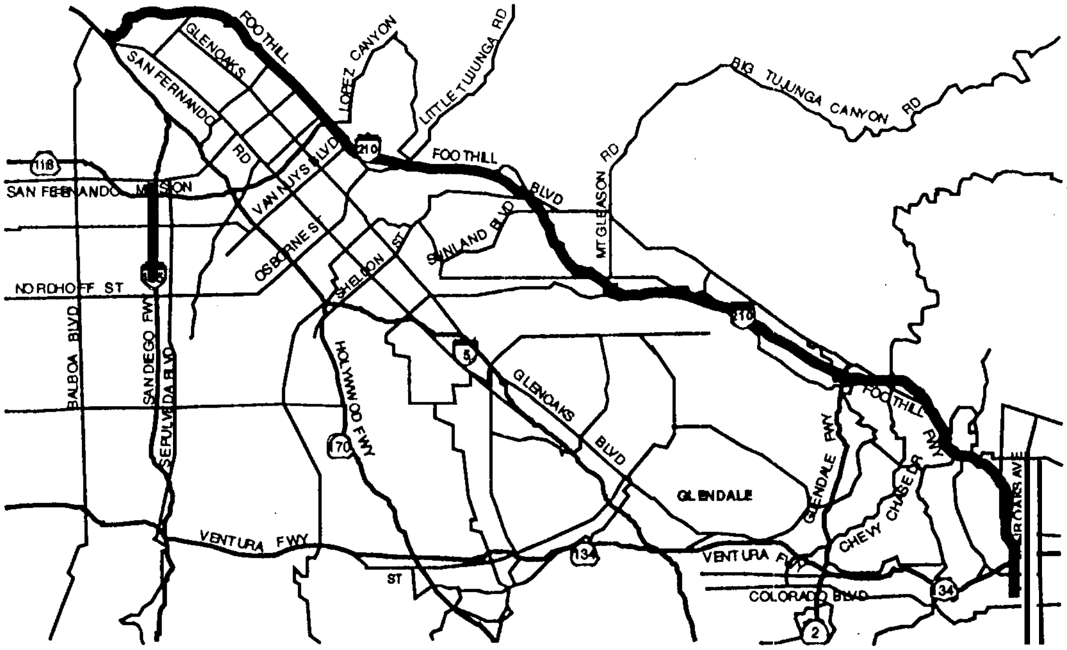

Figure 5 Interstate Propagation Test Route

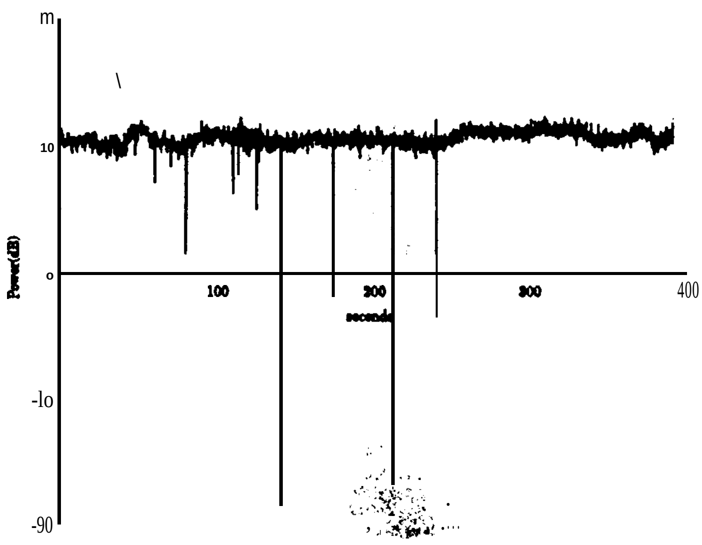

Figure 6 Typical Propagation Data from Interstate Test Route

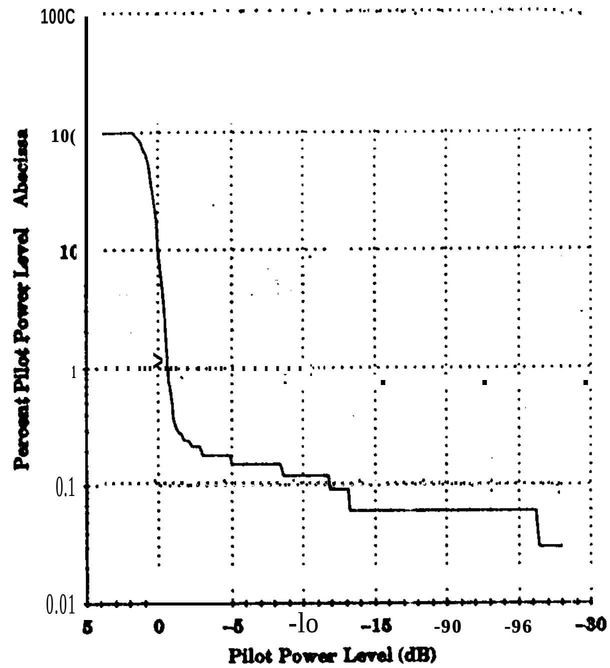

Figure 7 Interstate Test Route Cumulative Fade Distribution

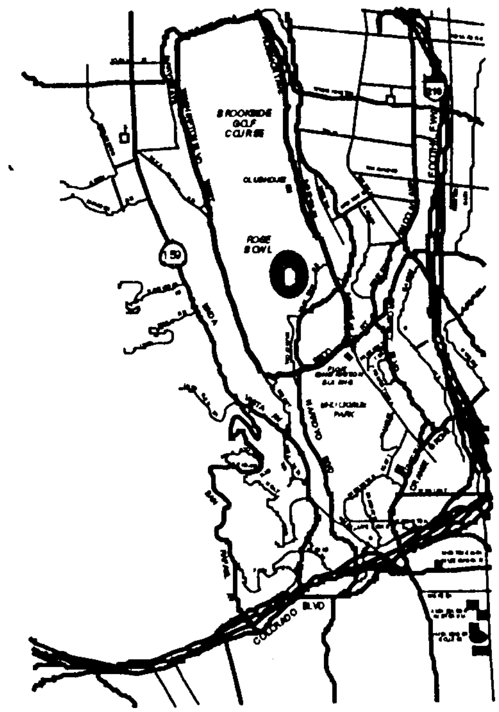

Figure 8 Surface Street Test Route

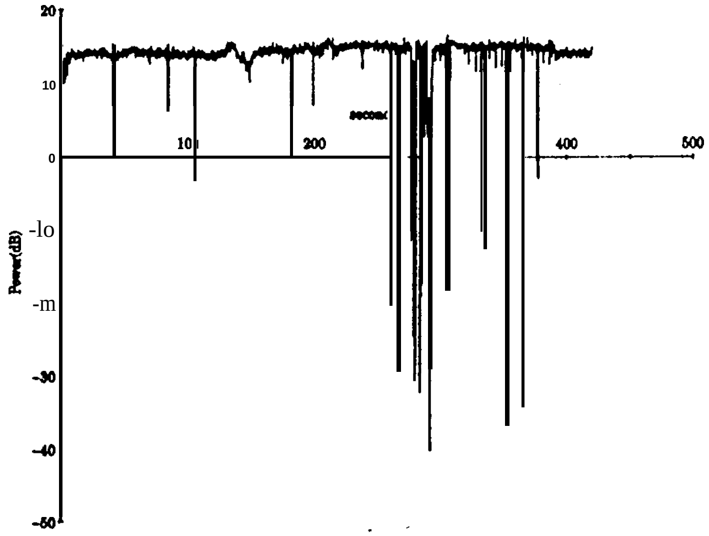

Figure 9 Typical Propagation Data from Surface Street Test Route

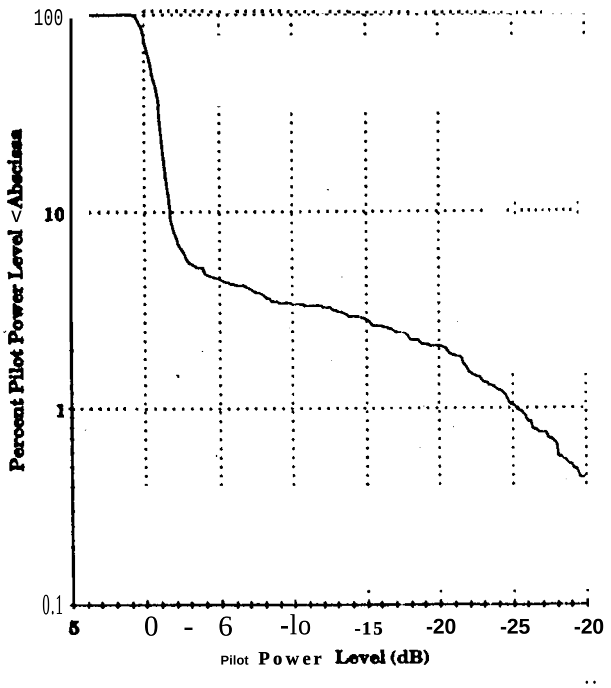

Figure 10 Surface Street Test Route Cumulative Fade Distribution

Figure 11 Antenna Size Comparison Between SNG Van of Today and Tomorrow